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ACTIVE STRUCTURAL FIBERS FOR MULTIFUNCTIONAL COMPOSITE MATERIALS

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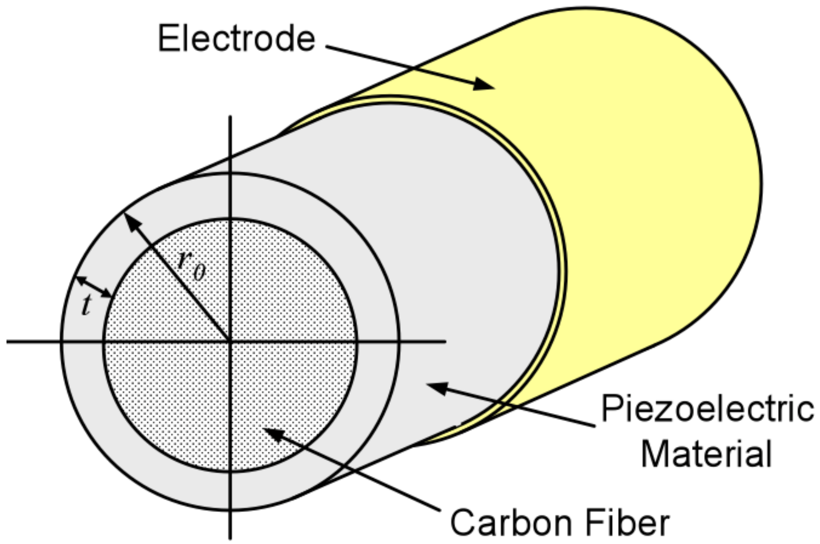
Multifunctional Materials

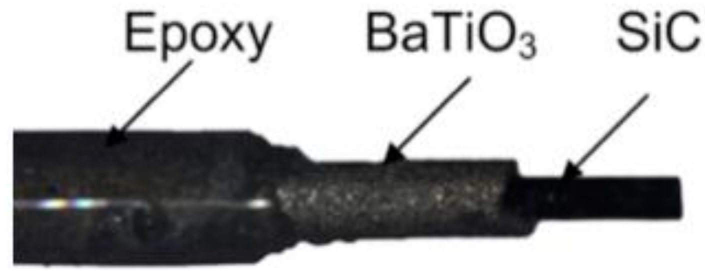
- Multifunctional materials are integrated systems that can perform several functions of an application from a single component of the system
- Examples of functional combinations
  - Structural plus ballistic and/or blast protection
  - Structural plus chemical
  - Structural plus damping
  - Structural capability plus power/ energy generation
  - Structural plus sensing
  - Structural plus self- decontamination.
  - Structural plus self-repair
  - Structural capability plus thermal management

Multifunctional Piezoelectric Fibers

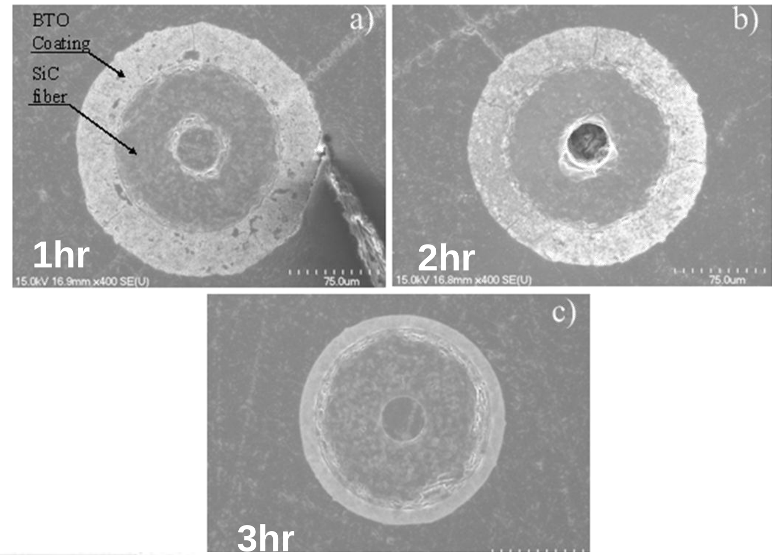
- Conductive fiber is coated in a piezoceramic layer
  - Carbon Fibers
  - Silicon Carbide Fibers
- Electrode applied to outer shell of the fiber allowing electric field to be applied through the radius of the fiber
- The material poled and used for sensing/actuation, structural health monitoring, damping or energy harvesting

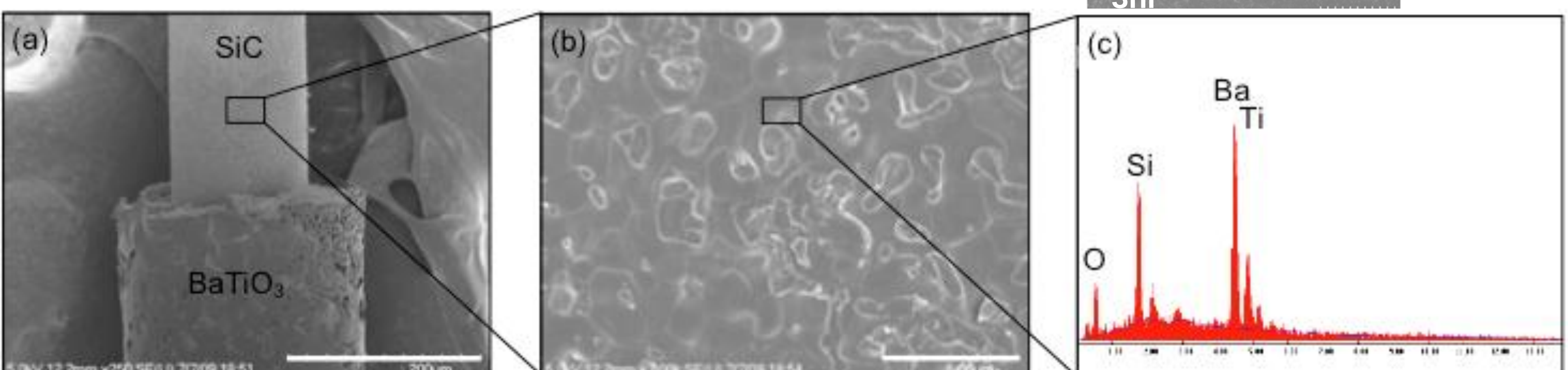


Multifunctional Structural Composites

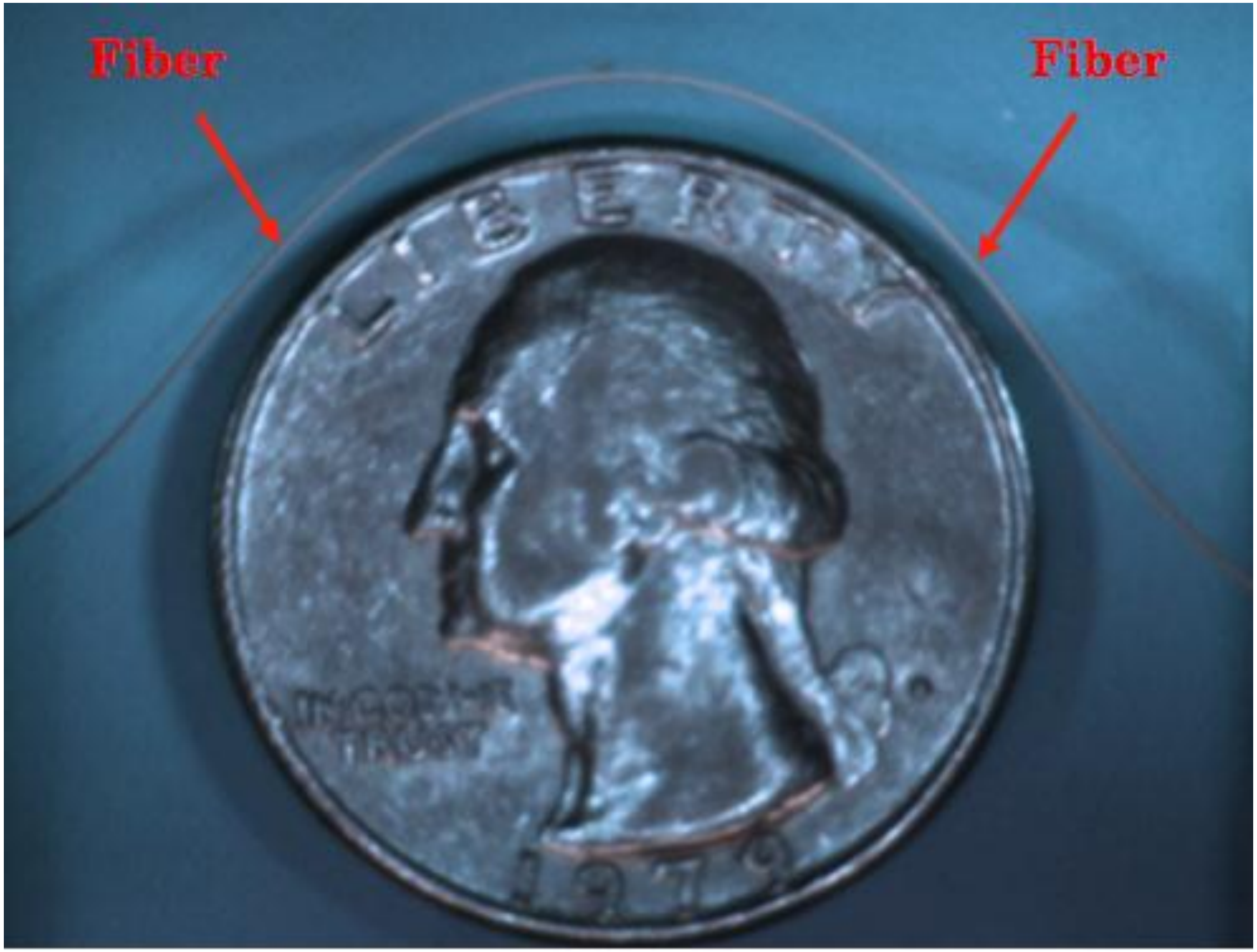


- Developing methodologies to integrate piezoelectric materials into structural materials
- Formulated models to predict the behavior of multiphase piezoelectric composites

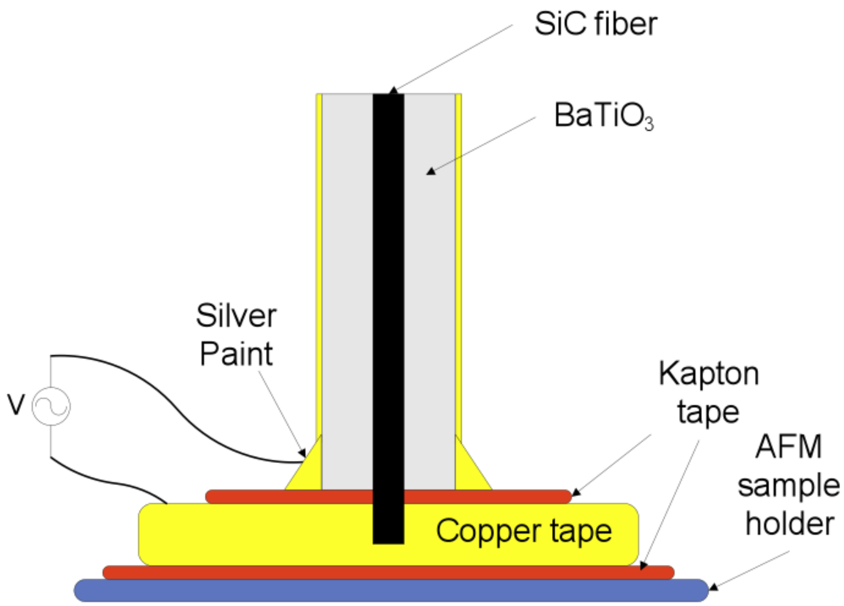


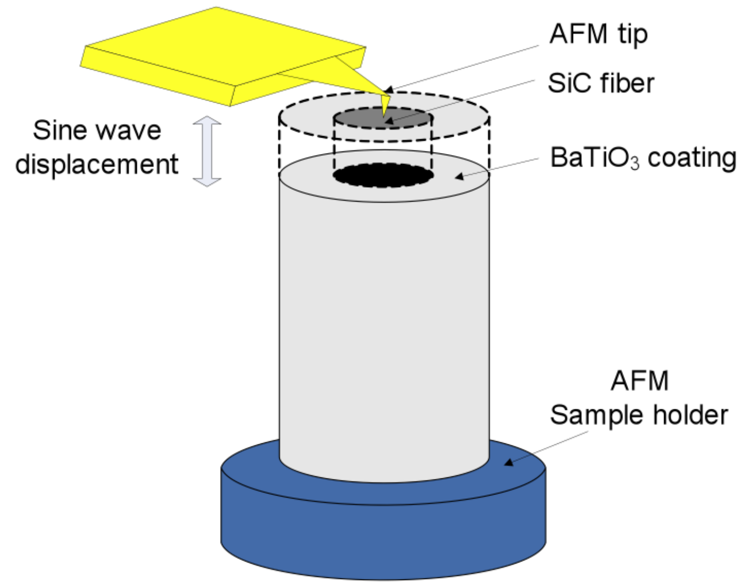


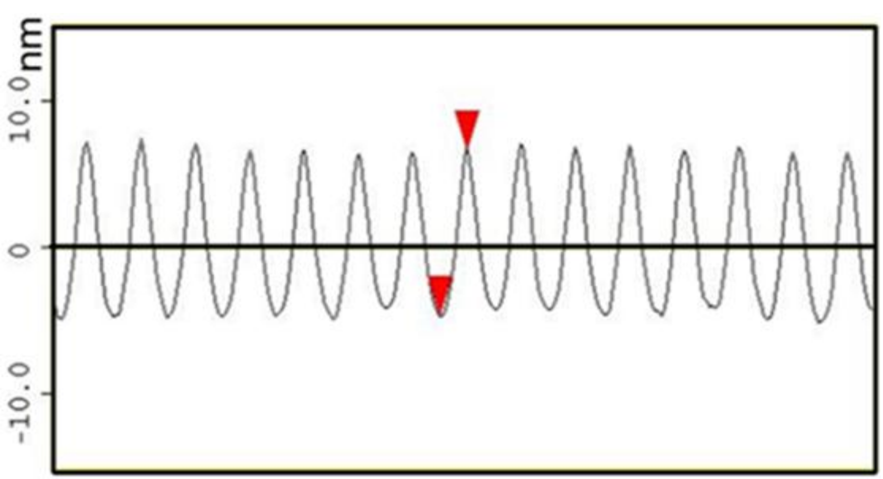
Active Fiber is Flexible After Sintering

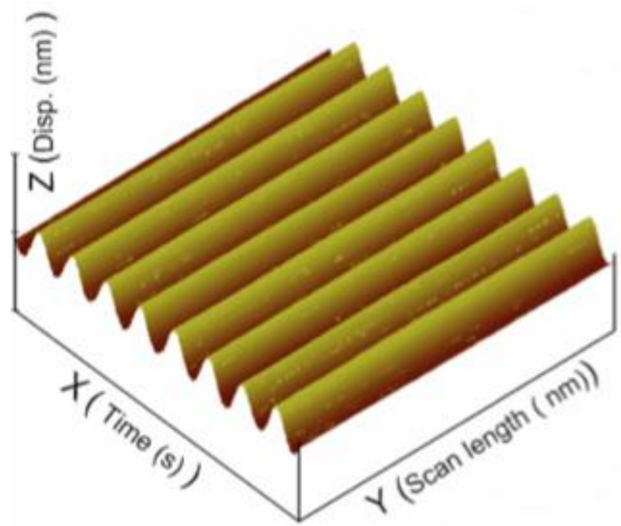


Experimental Testing of Fiber



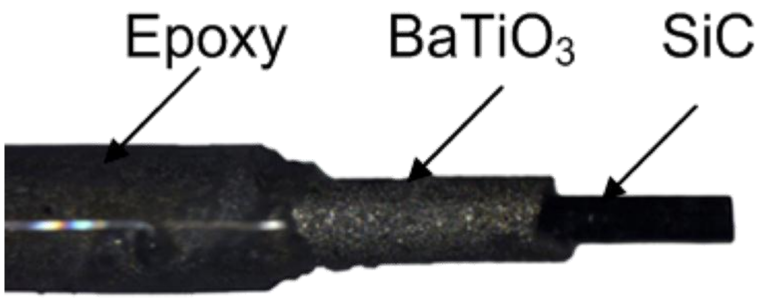


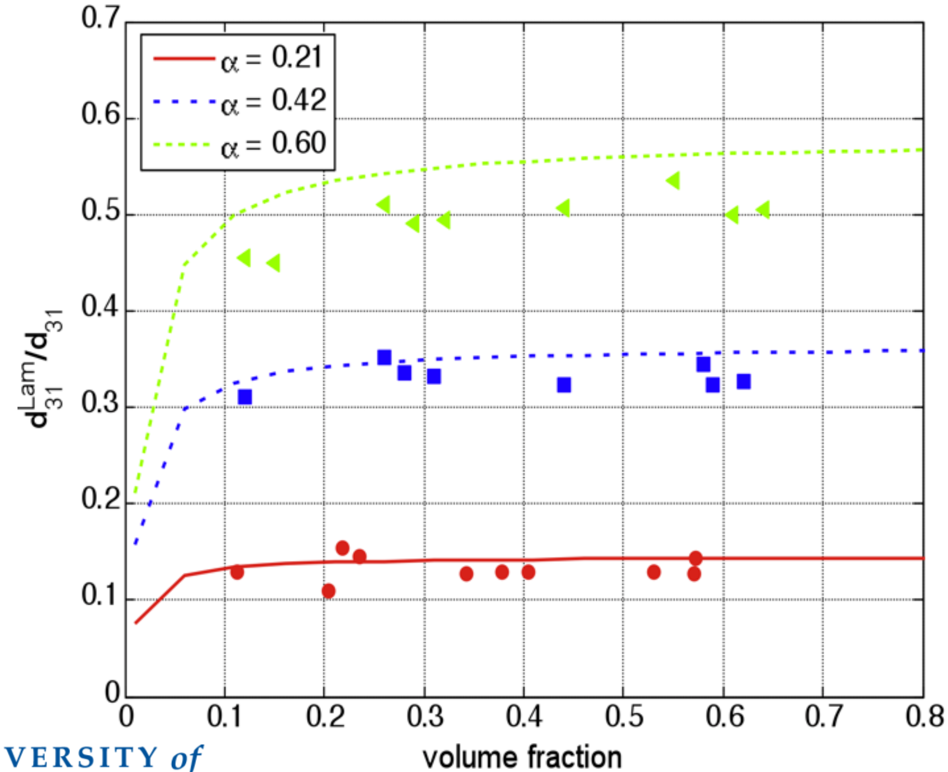




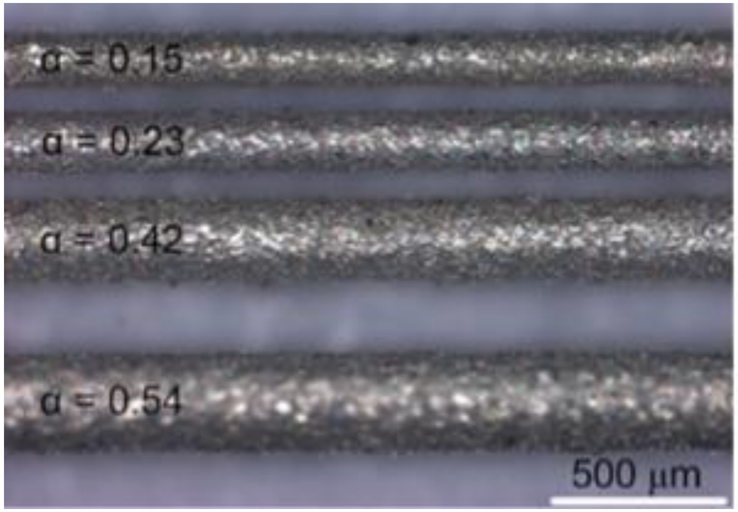
Electromechanical Coupling of Lamina

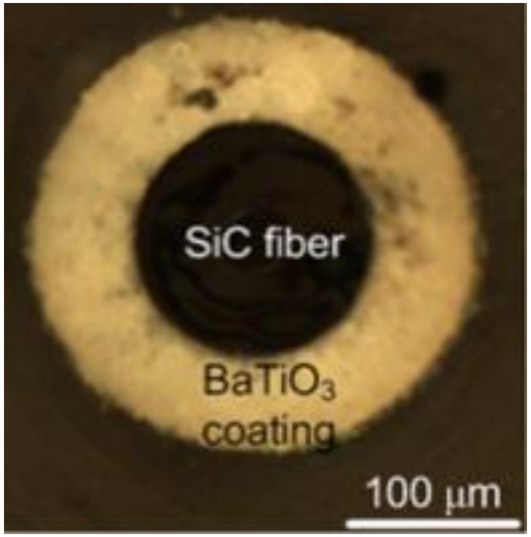
- Concentric single fiber lamina formed
- AFM used to measure the piezoelectric coupling coefficient
- Results indicate structural composites with coupling greater than many pure phase piezoelectrics can be produced



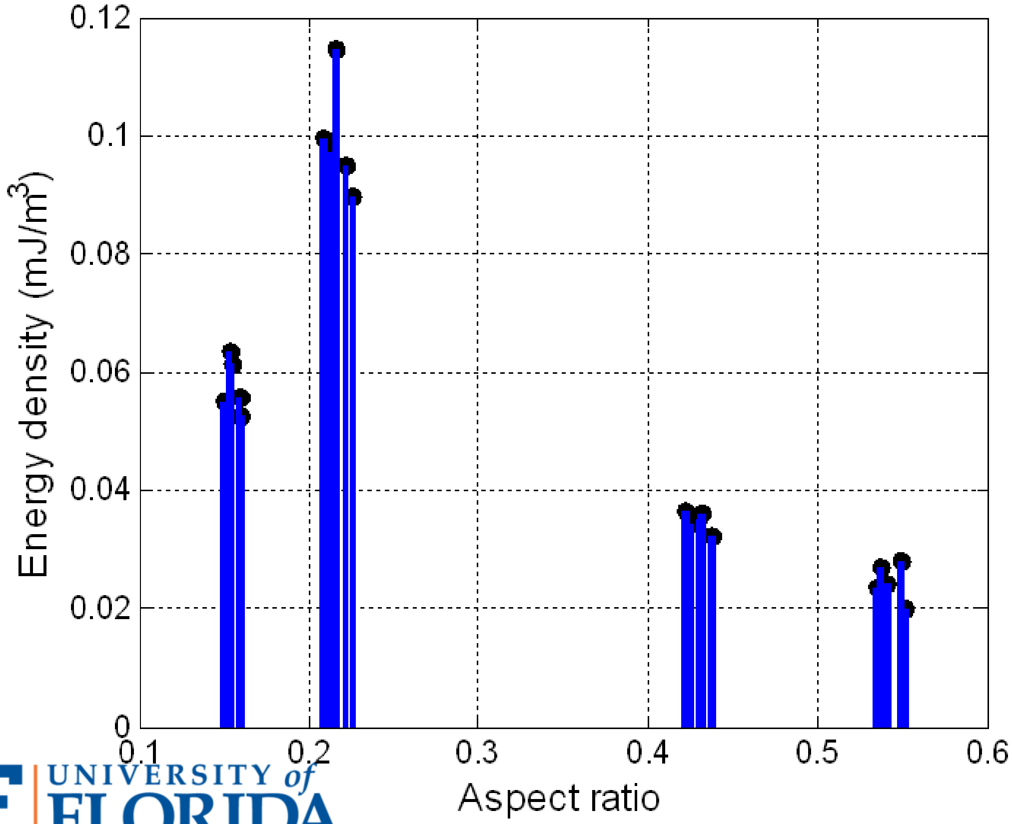


Energy Storage Characterization





- Dielectric constant of 1150
- Breakdown strength of 7 MV/m
- Maximum energy density of ~0.1J/cm^3



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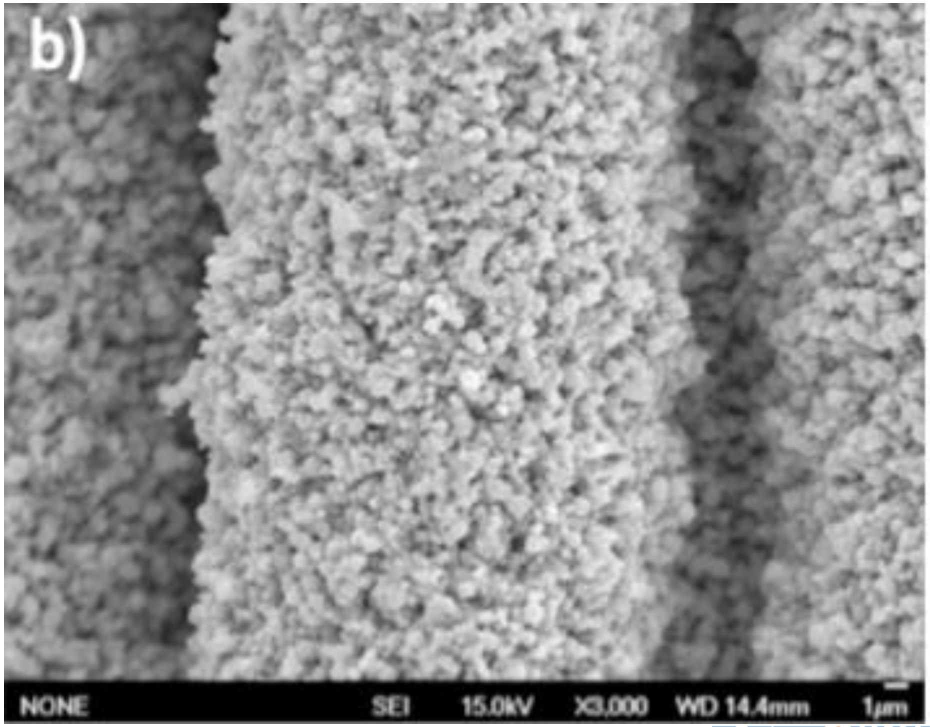
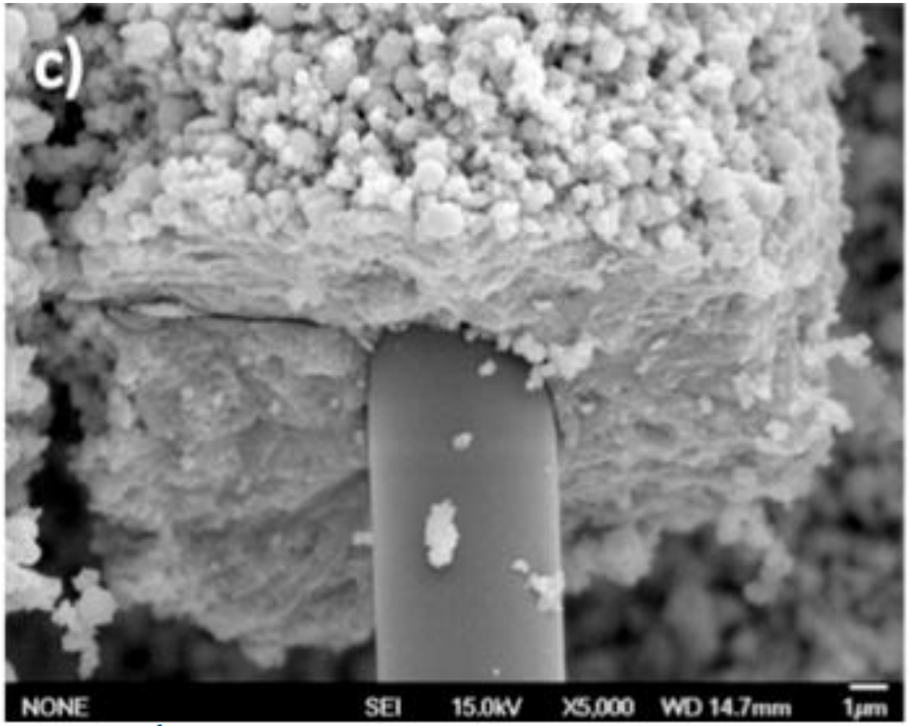
Thick Film Piezoceramics on Carbon Fiber

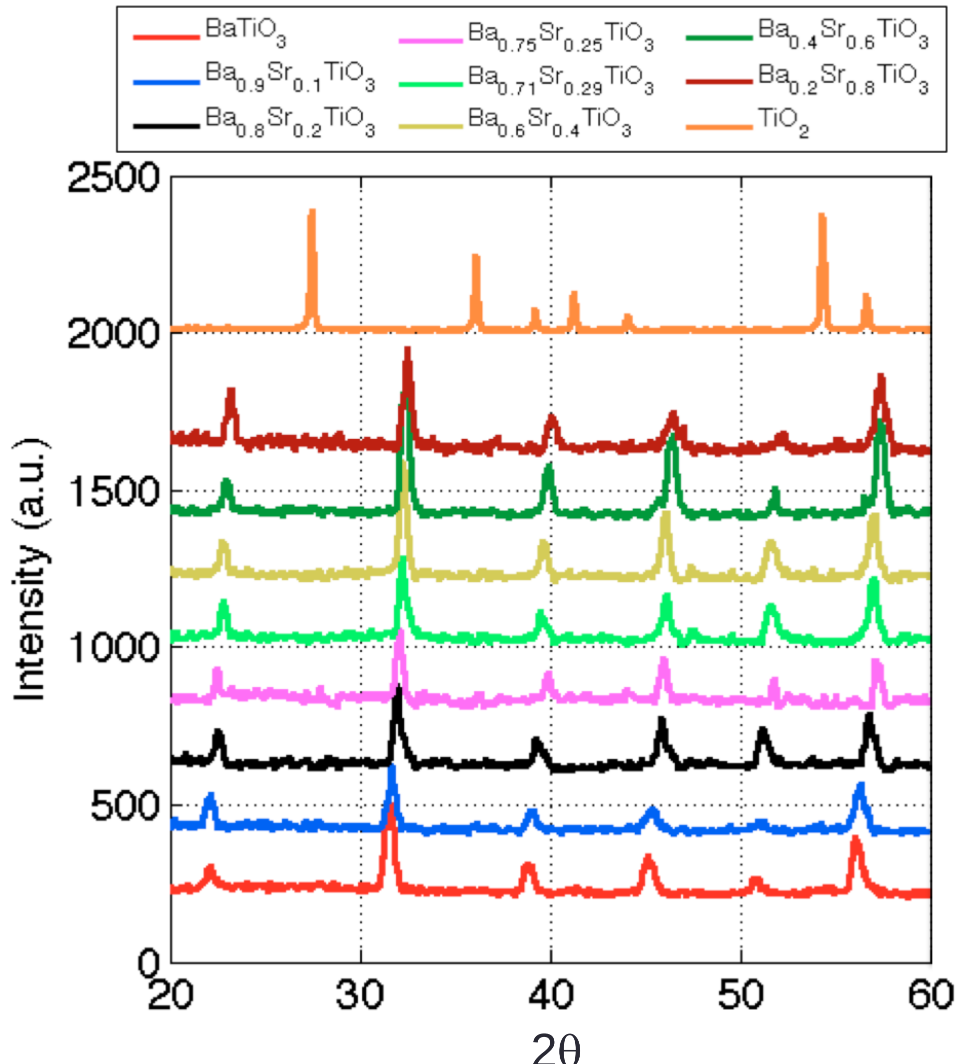
- New program looking at the reduction of the fiber size to be compatible with carbon fibers
- Have developed a new solution based growth process for piezoceramic compositions with high electromechanical coupling





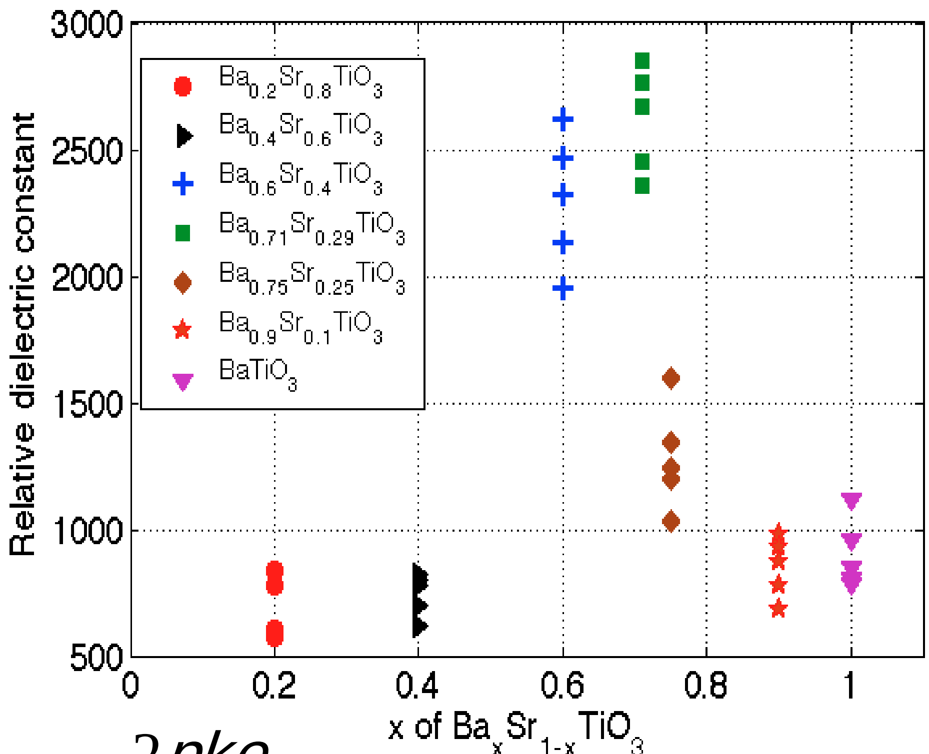
X-ray Diffraction of BST Coatings

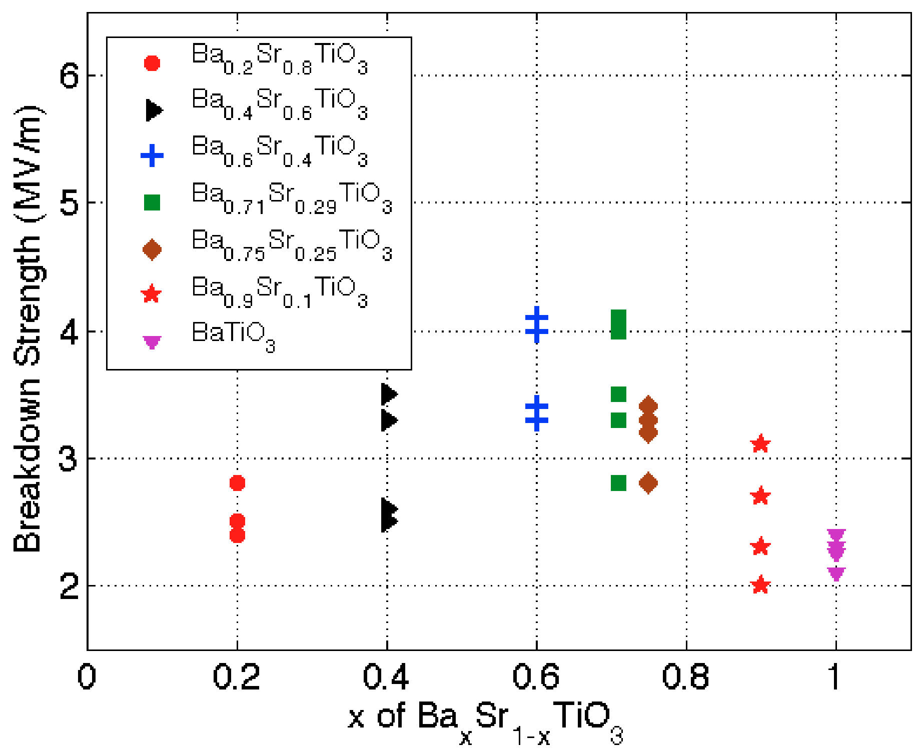
- $Ba_xSr_{1-x}TiO_3$ films can be grown with stoichiometry control
- Process allows for control of the film thickness from ~500nm to 20μm
- Other perovskite compositions can be synthesized



Electrical Characterization of Fibers

- Dielectric constant similar to that of EPD films
- Breakdown strength low, potentially due to current defect density, highest at curie temperature





$$C = \frac{2pk e_0}{\ln(b/a)} L$$

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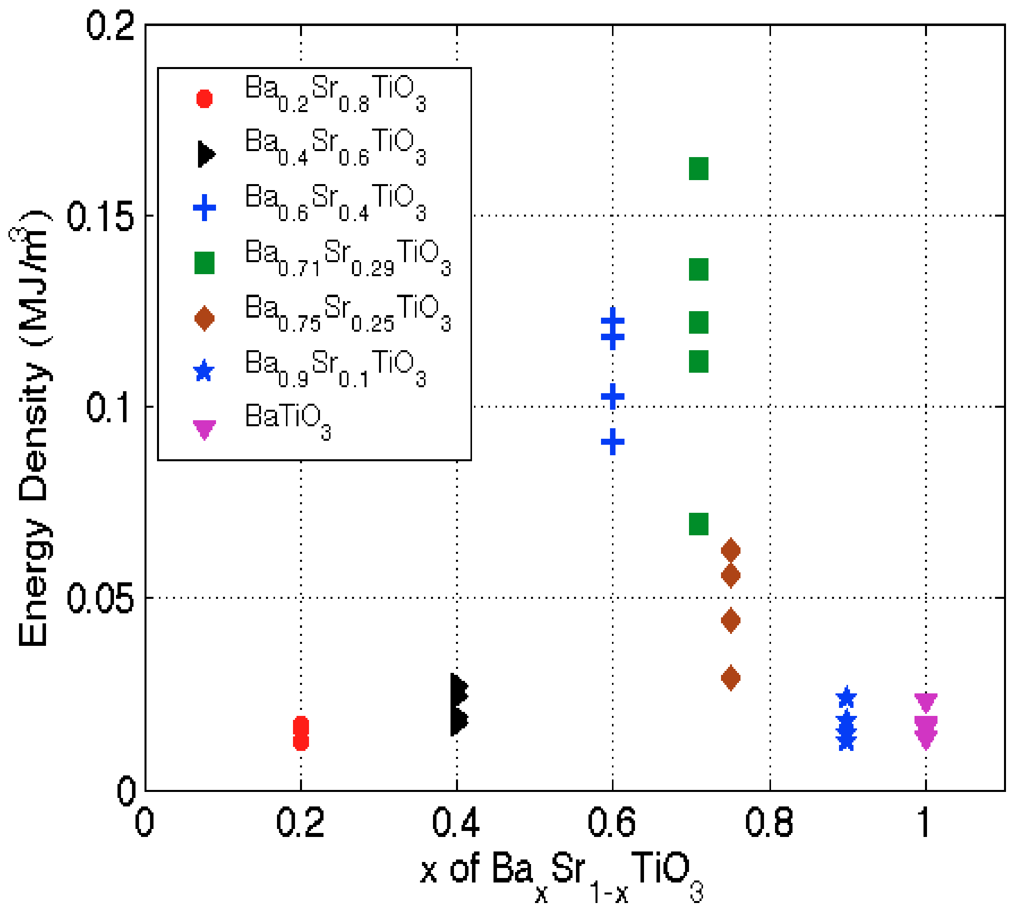
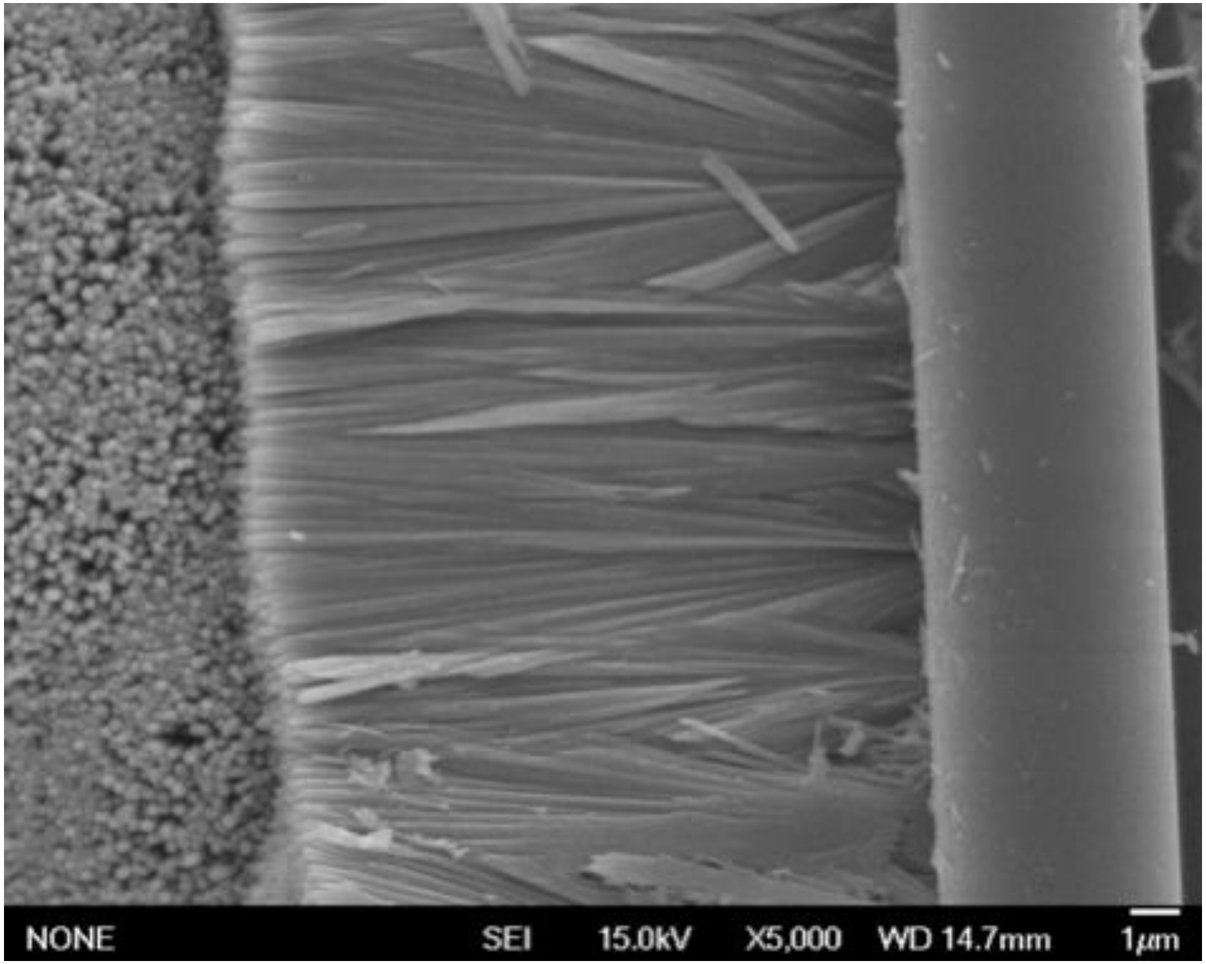
Energy Density of BST Thick Films

- Maximum energy density of 0.1202J/cm^3
- Largest energy density occurs when Curie temperature is near ambient
- Energy density of BST ~20% of the sintered films
- Lower breakdown and increased defect density

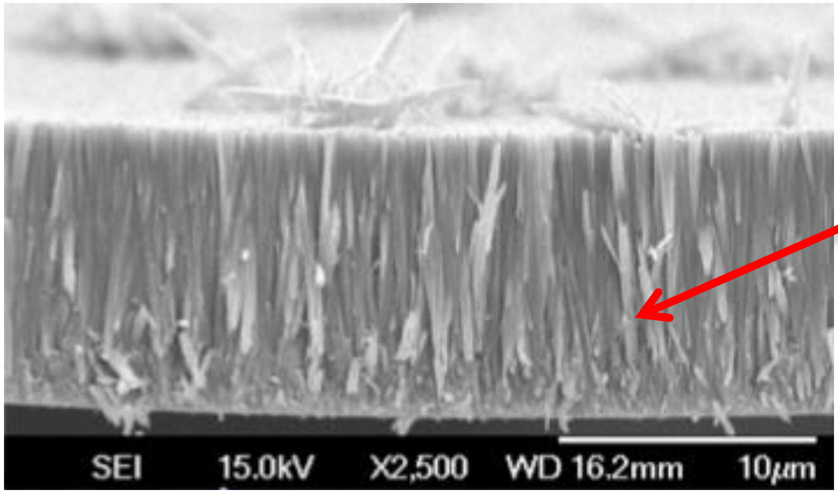


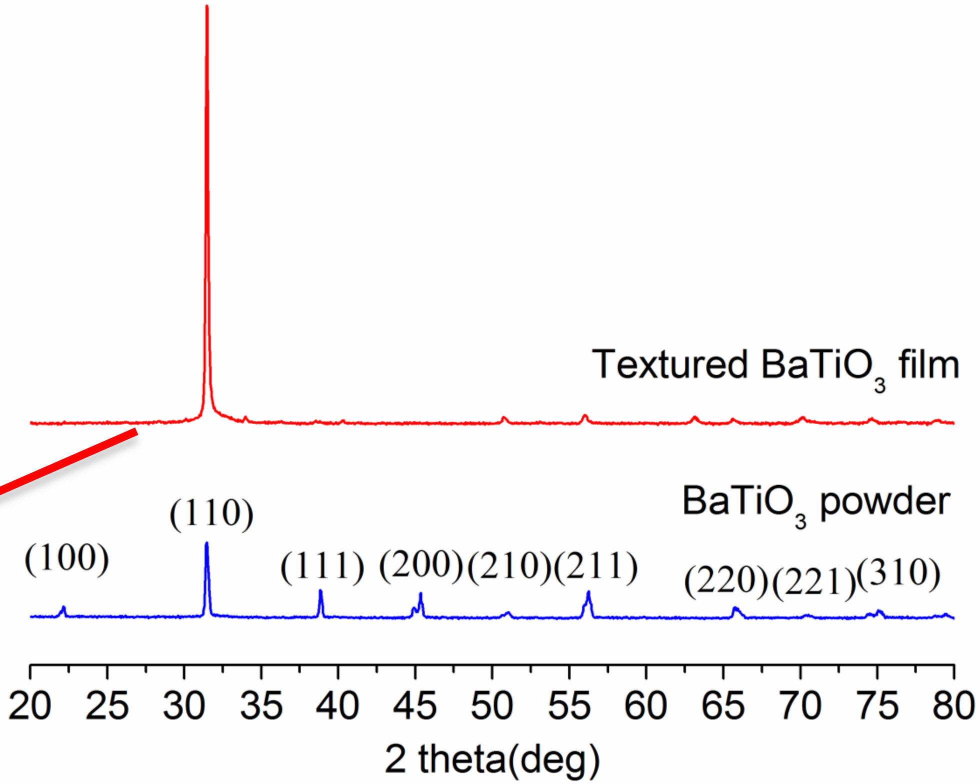
Textured Films on Fibers



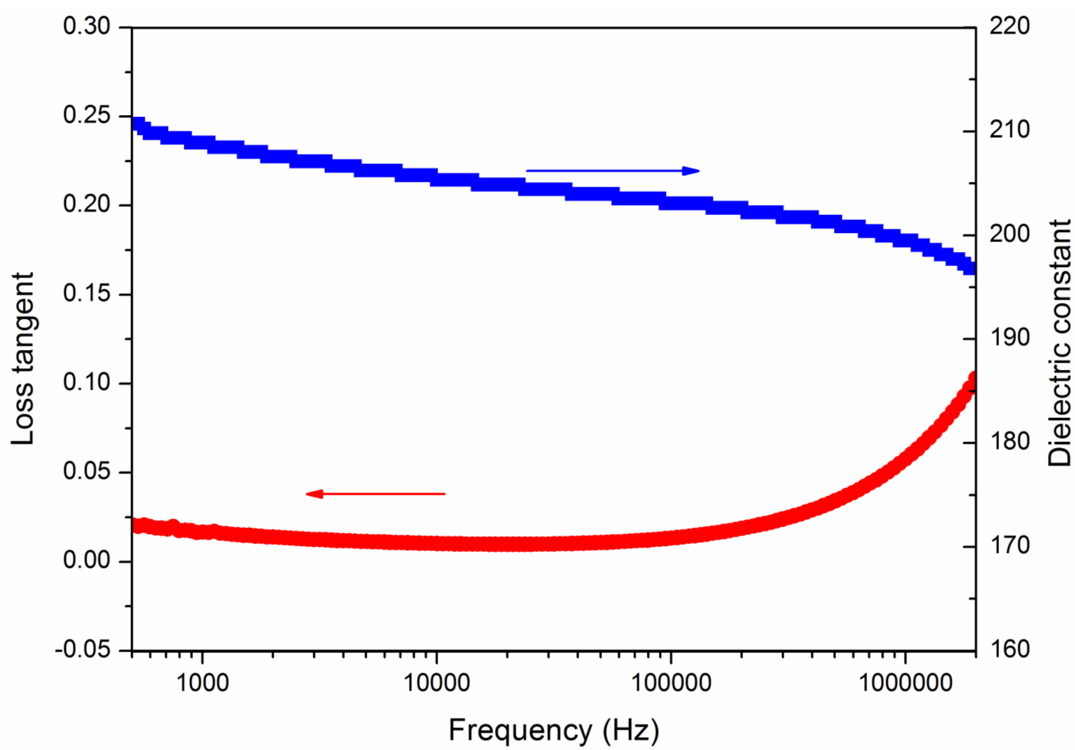
XRD Analysis of Textured Films

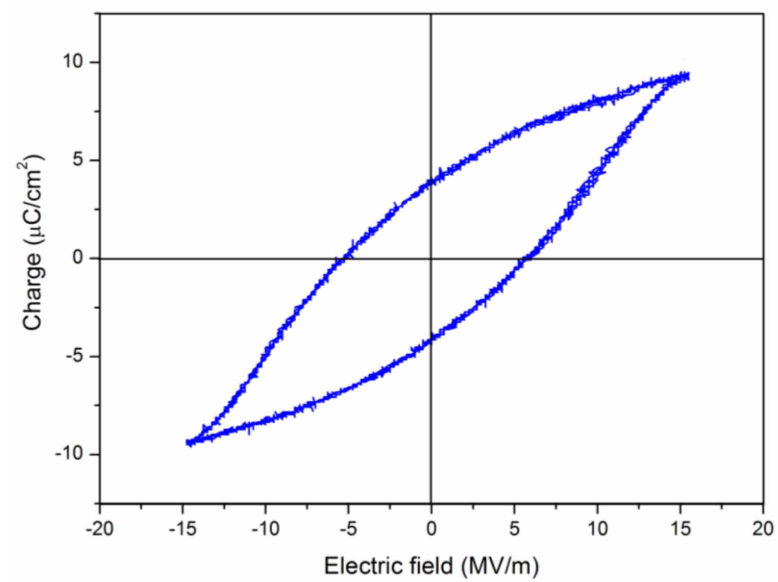
- Crystallographic texture can lead to improve dielectric and electromechanical coupling





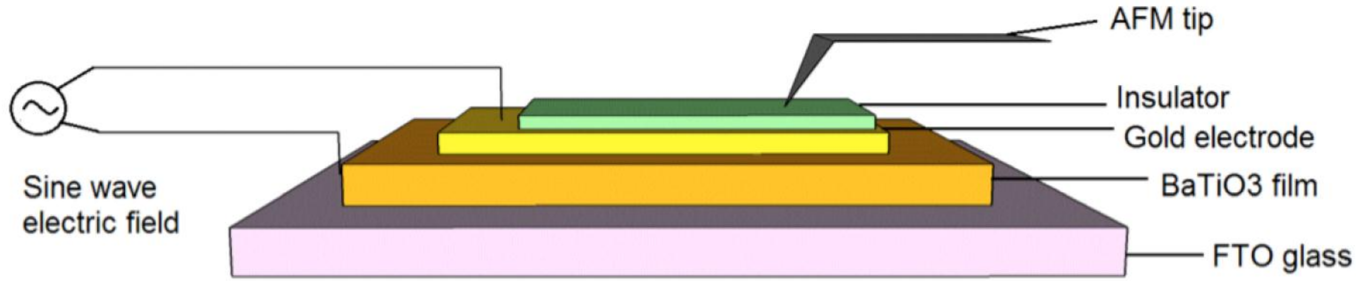
Dielectric constant and Loss tangent





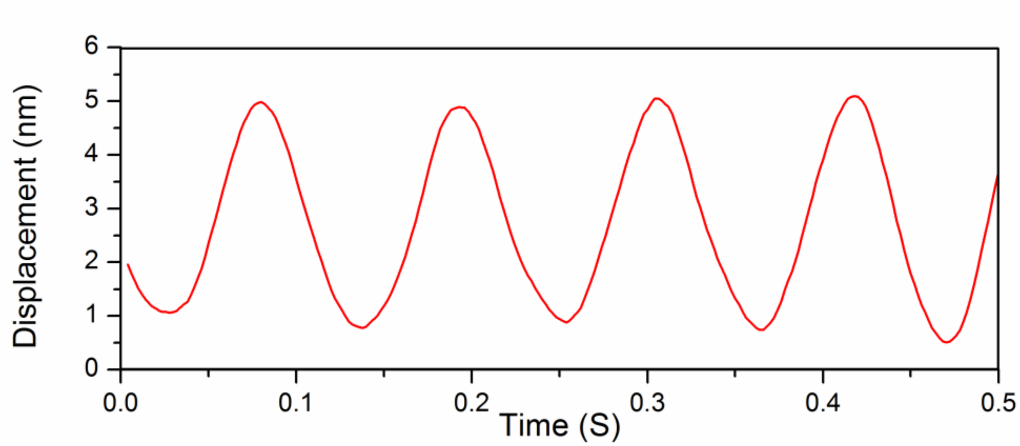
- Dielectric constant is 210 at 1KHz, and 196 at 2MHz.
- Loss tangent is 0.02 at 1KHz, and 0.09 at 2MHz.

Piezoelectric Response



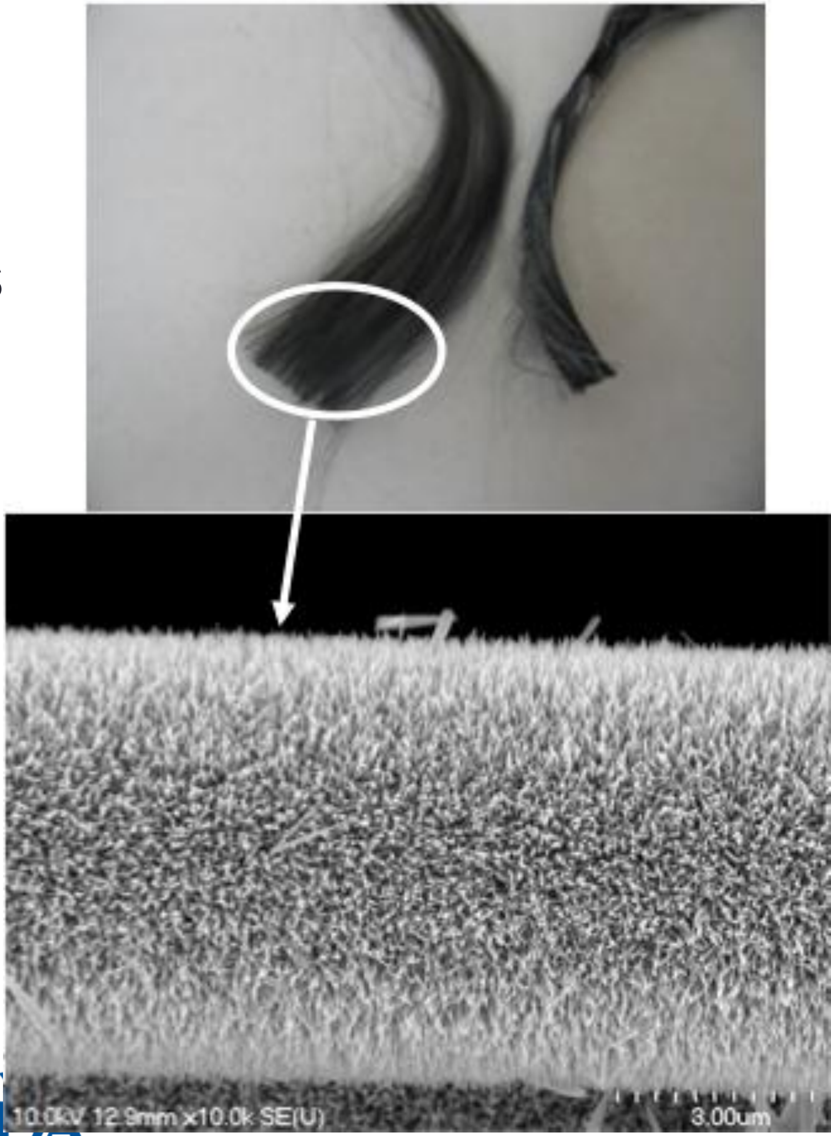
The sample was poled with 12.5KV/mm (+100V) for 1 hour

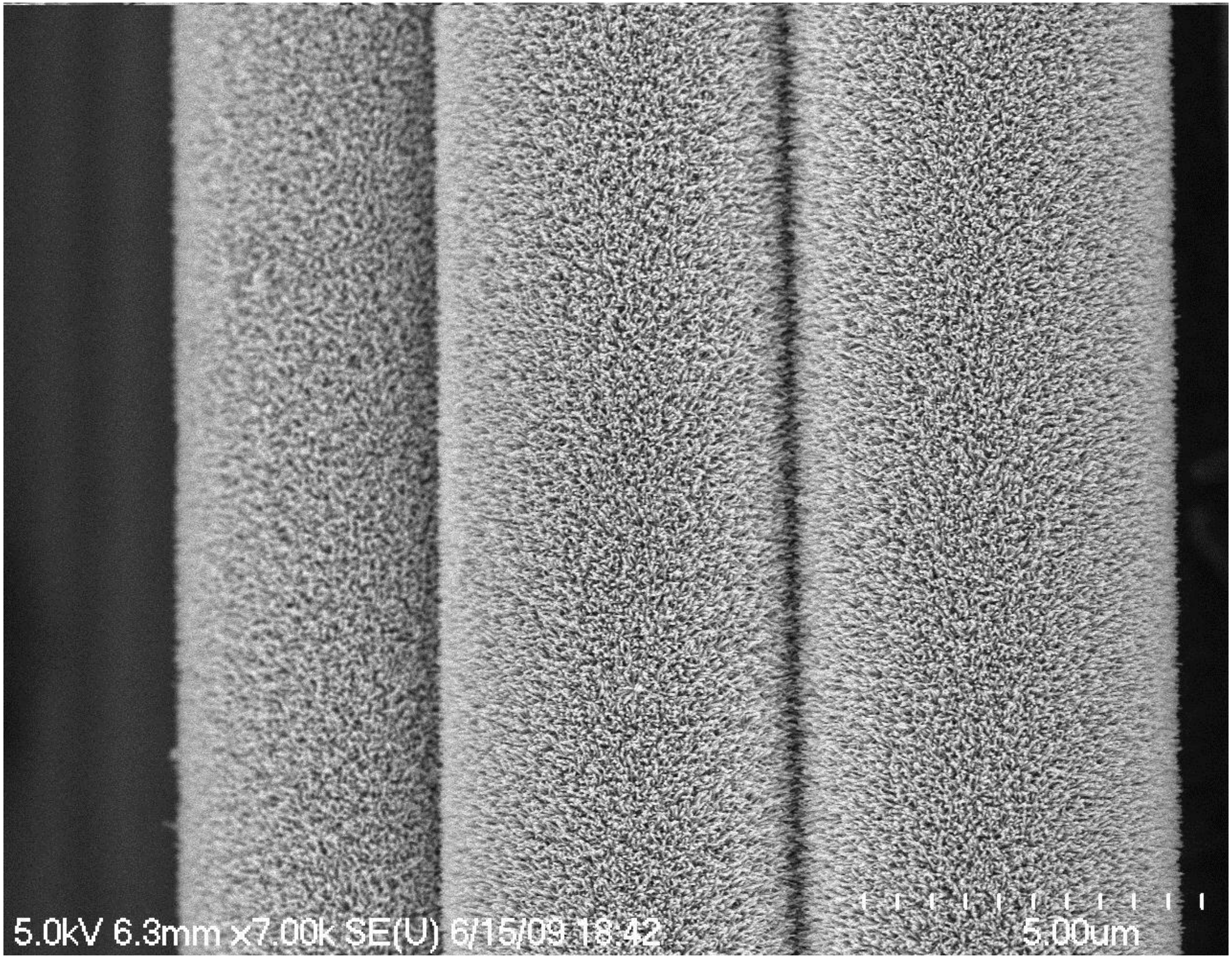
- 0-80V 10 Hz sine wave applied with displacement measured by AFM
- The film has a d_{33} coupling coefficient of 50 pm/V
- High coupling for thin films



ZnO Growth on Carbon Fibers

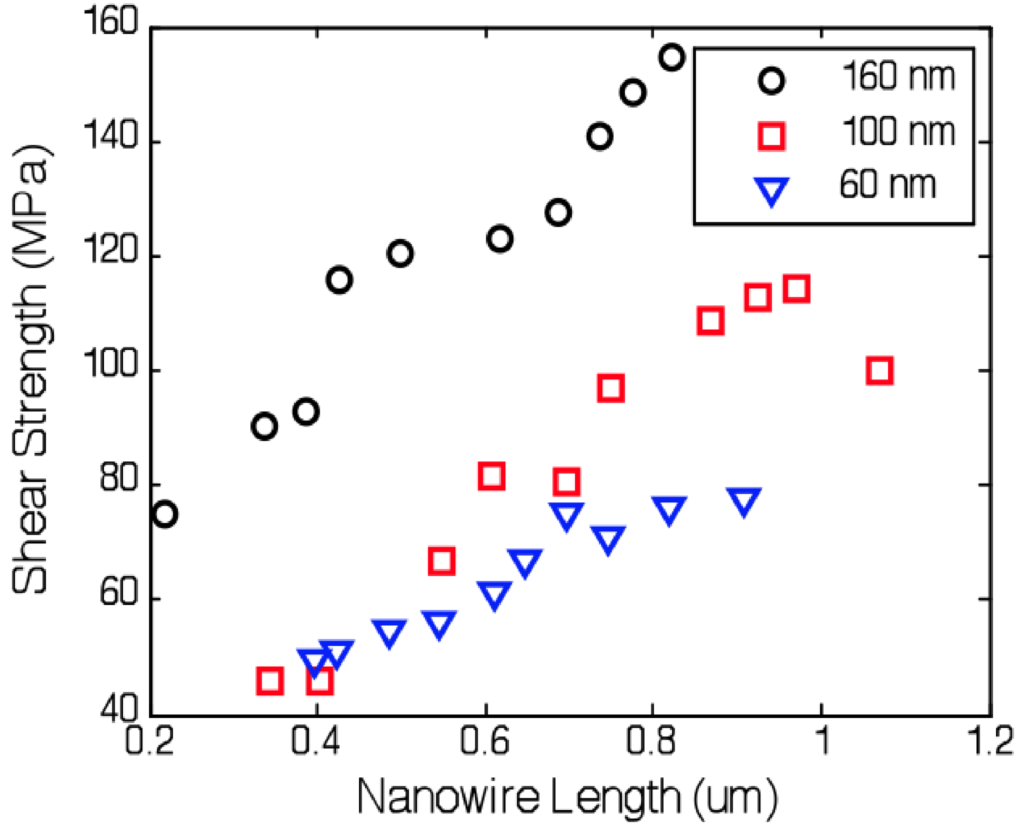
- Solution based growth techniques allow uniform coatings
- Process carried out at temperatures < 90° C
- Low temperature allows nanowire growth on polymeric fibers
    - Kevlar, Vectra, etc.
- Nanowire act to reinforce and functionally grade the interface
- Nanowires are piezoelectric and semiconductive




5.0kV 6.3mm x7.00k SE(U) 6/15/09 18:42
5.00um

Nanowire Morphology and Interface Strength

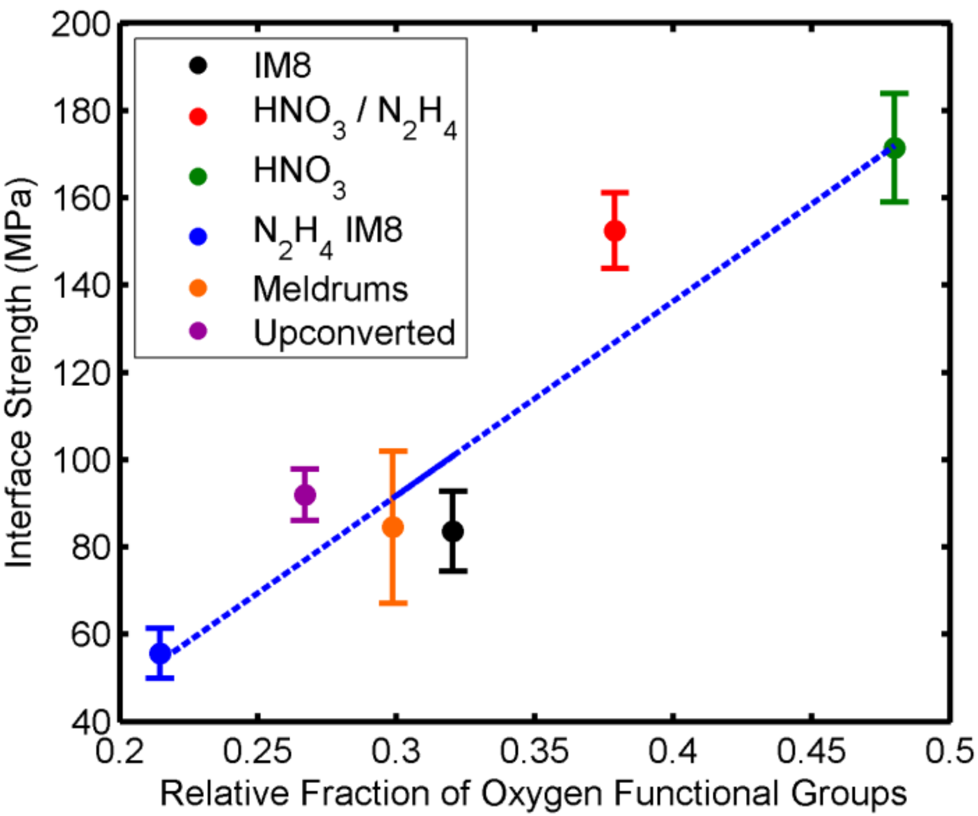
- Range of nanowire lengths characterized for three separate diameters
- Up to a 3.28 times increase in interfacial strength
- Interfacial strength shows a clear dependence on nanowire morphology
- Increased nanowire diameter and length increases interface strength



3.28 times increase from 45.72 to 154.64 MPa

Surface Chemistry and Interface Strength

- Functionalization produces wide variety of functional groups and oxidation states
- Need a range of functionalization procedures that selectively produce different surfaces
  1) Nitric acid oxidation
  2) Reduction with hydrazine hydrate
  3) Nitric acid oxidation followed by reduction with hydrazine hydrate
  4) Grafting of meldrum's acid to surface hydroxyl groups
  5) Permanganate oxidation
- The five functionalization treatments produced a range of hydroxyl, ketone and carboxylic acid surface coverage



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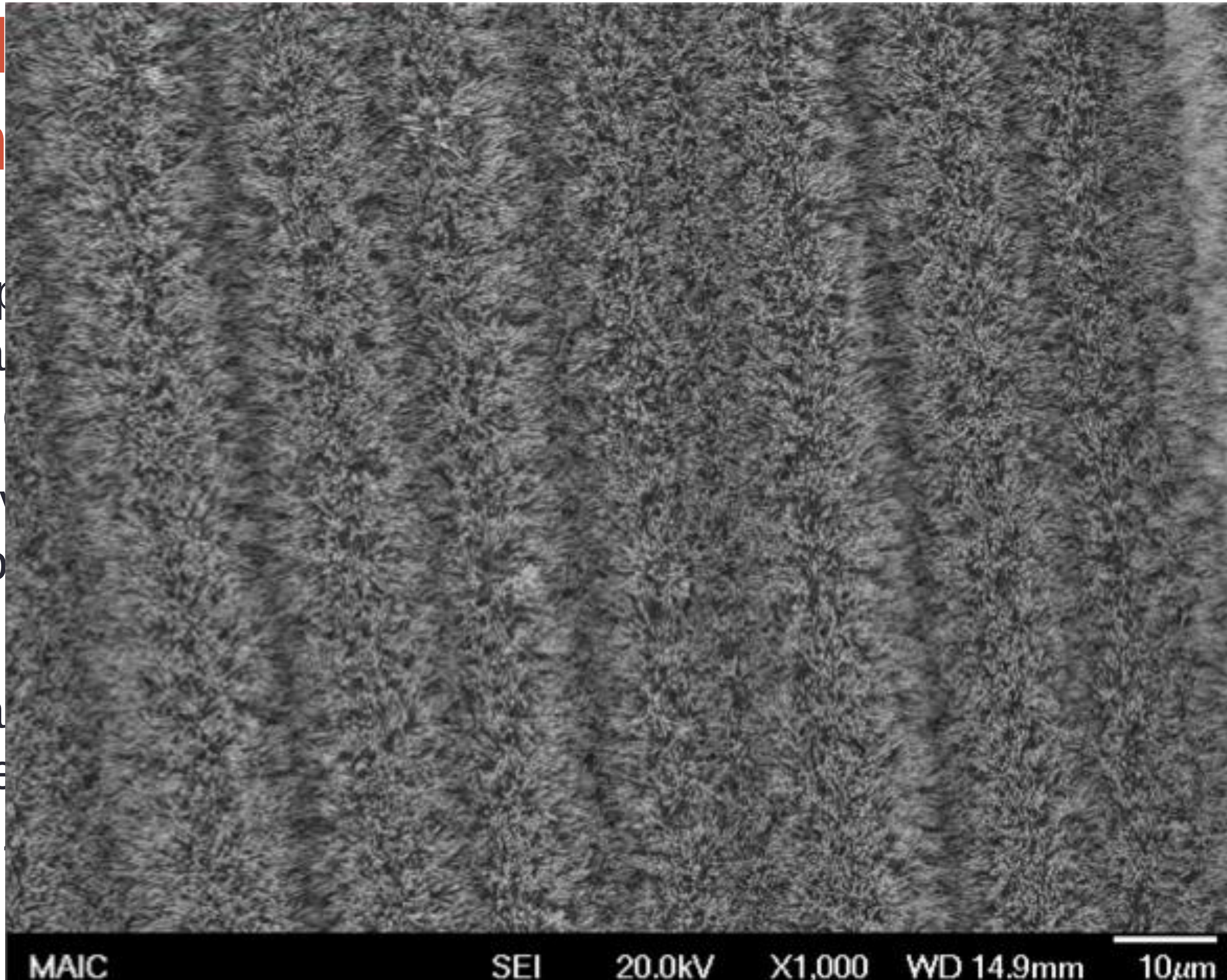
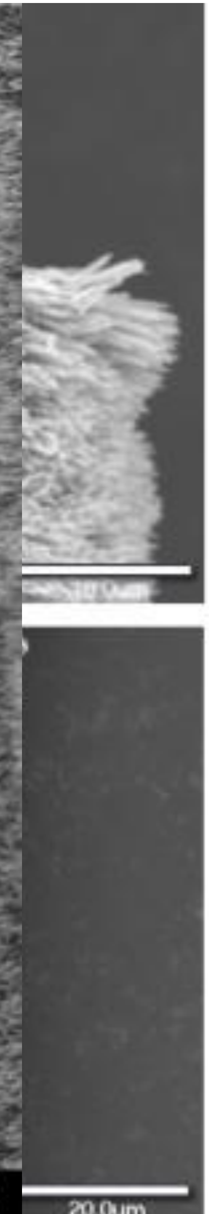
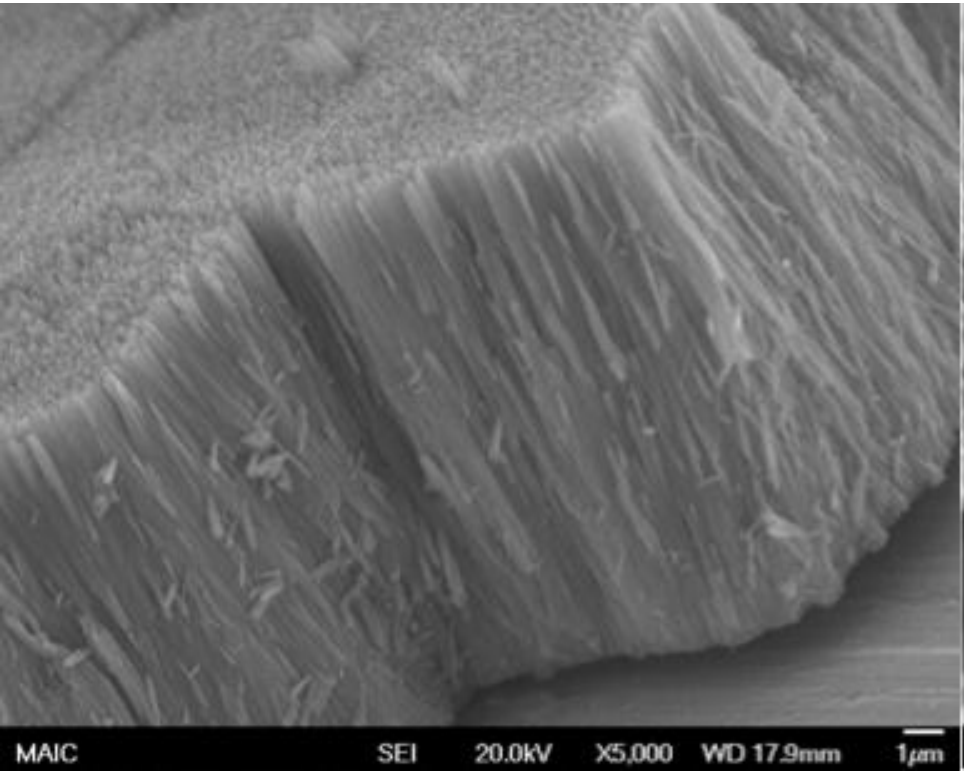
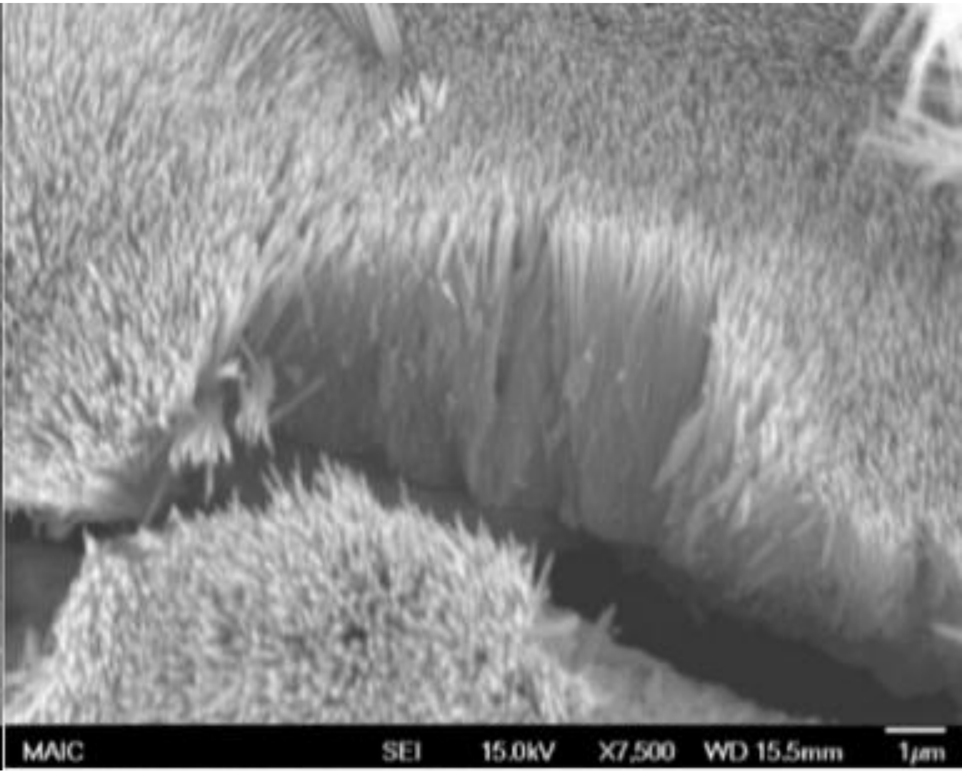




Textured Films Terminated in Nanowires





Questions?

Acknowledgements

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